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GAMMA-RAY LINE INTENSITIES FOR DEPLETED URANIUM

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Abstract Measurements of the gamma-ray line intensities from depleted uranium allowed us to determine which of two conflicting previous experiments was correct. For the 1001-keV line we obtained a branching ratio of 0.834 ± 0.007, in good agreement with one of the previous experiments. A table compares our intensities for several lines with those obtained in previous experiments.

INTRODUCTION

The gamma-ray line intensities from depleted uranium are necessary for assaying material in nuclear safeguards and for calculating the gamma-ray flux from objects containing depleted uranium. Most of the gamma rays are produced by ^{234m}Pa and ^{234}Pa in equilibrium with ^{238}U (Fig. 1). For the strong 1001-keV from ^{234m}Pa, the Table of Isotopes[1] and the Nuclear Data Sheets[2] quote a branching intensity of 0.59% based on a 1963 reference.[3] A

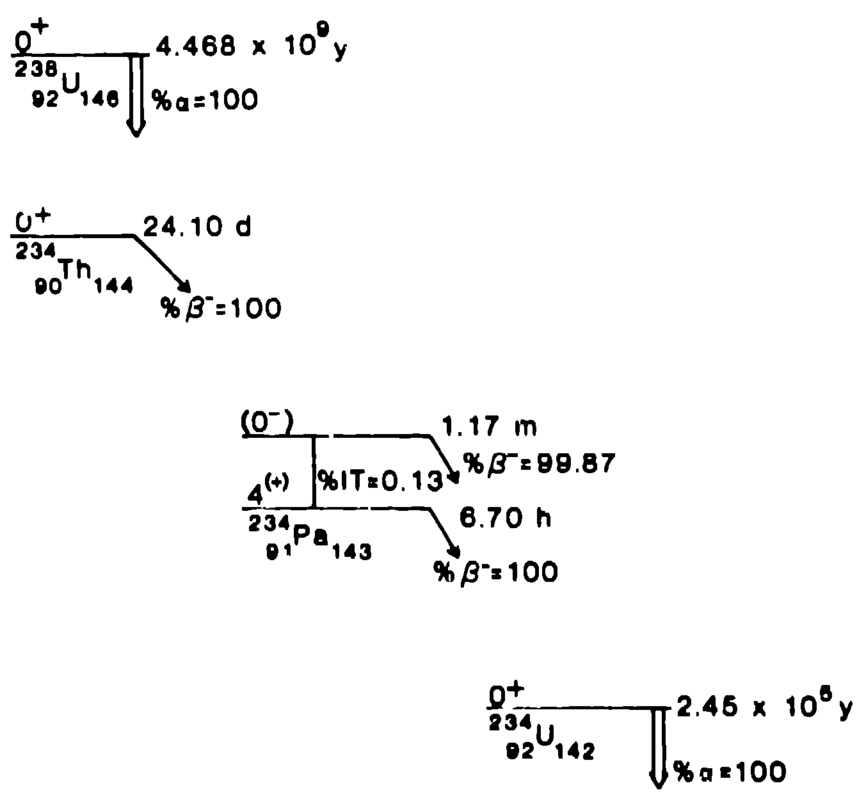

FIGURE 1 Part of the decay chain for ^{238}U.

1971 report from the Lawrence Livermore National Laboratory gives 0.828%.[4] Some difficulties in obtaining agreement between calculated and measured fluxes from objects containing depleted uranium prompted us to remeasure the intensities of lines from depleted uranium.

EQUIPMENT AND METHODS

For the measurements, we used three high-purity germanium detectors, five samples and two distances in many combinations. The resolutions (full width at half maximum) and the efficiencies (at 1332 keV relative to the efficiency of a 7.62 cm long by 7.62 cm diameter NaI(Tl) detector) of the three detectors were 1.98 keV and 19.8%, 1.90 keV and 11.3%, and 1.73 keV and 31.7%. Four of the samples were disks with the following masses: 0.5 g, 5.8 g, 11.3 g, and 22.4 g. The fifth sample was a 270.0-g foil 15.9 cm long and 10.8 cm wide. Each sample contained 0.997% ^{238}U by weight. The two distances between the source and the detector were 25 cm and 100 cm. An 8192-channel analyzer acquired the pulse-height distributions.

To calibrate the efficiency of the system we used a radioactive source from the US National Bureau of standards (NBS) containing ^{125}Sb, ^{154}Eu, and ^{155}Eu. The uncertainties in most of the line intensities were less than 0.7%. We also compared several commercial sources such as ^{88}Y and ^{60}Co with larger uncertainties to the NBS source to verify that there were no gross inconsistencies. Some calibration measurements were made with just the NBS source present; for others, the NBS source and the uranium sample were both present and located at the same distance.

Analysis of the measurements required the determination of peak areas. A program called FITEK[5] determined some of the peak areas by fitting a Gaussian function with tails to the peaks. Other peak areas were determined in the pulse-height analyzer by subtracting a straight-line approximation for the continuum under each peak. Separate background measurements were used to correct all peak areas.

Two methods were used to determine an efficiency curve from the efficiency calibration peak areas. The first method involved fitting the efficiency points with the function

$$\ln E_p = \sum_{i=1}^{NMAX} A_i (\ln E)^{i-1}$$

where E_p = efficiency, A_i = coefficient, E = energy in keV, and NMAX = maximum number of parameters, usually eight. The second method was simply manually drawing a curve through the efficiency points.

RESULTS

Among the many gamma-ray lines from depleted uranium (Fig. 2) we chose the five lines with energies 742, 766, 786, 946, and 1001 keV for analysis. These lines are the strongest ones in the region where our efficiency curves are most accurate. The Table shows that our values are in good agreement with those of Ref. 4. Our value of 103.7 ± 0.9 photons/s/g of ^{238}U for the 1001-keV line corresponds to a ^{234m}Pa branching ratio of 0.834 ± 0.007; the value in Ref. 4 is 0.828 ± 0.008.

We have calculated recommended values for eight strong lines (last column of the Table). These values are averages weighted by the square of the uncertainties from three sources: Ref. 2 normalized, Ref. 4, and the present work. The weighted average of the value of 103.0 ± 1.0 from Ref. 4 and the value of 103.7 ± 0.9 for the 1001-keV line is 103.4 ± 0.7. We used this value to normalize the values in Ref. 2. The uncertainties in column two of the Table include a 14% uncertainty in the overall normalization added by Ellis-Akovali;[2] we omitted this uncertainty in our weighting procedure. Values for lines not shown in the Table can be calculated with a similar weighting procedure.

TABLE Specific activities of lines from depleted uranium.

Energy (keV)	Nuclear Data Sheets[a]	Livermore[b]	Present Work	Recommended
258	7.1 ± 1.0	9.1 ± 0.3	---	9.4 ± 0.2
742	7.4 ± 1.0	11.8 ± 0.2	12.1 ± 0.7	11.65 ± 0.18
766	25 ± 4	38.9 ± 0.4	41.4 ± 0.9	39.1 ± 0.4
786	4.5 ± 0.6	6.84 ± 0.14	6.8 ± 0.5	6.73 ± 0.12
946	2.8 ± 1.1	4.41 ± 0.09	4.2 ± 0.5	4.40 ± 0.09
1001	73 ± 10	103.0 ± 1.0	103.7 ± 0.9	103.4 ± 0.7
1738	1.8 ± 0.3	2.64 ± 0.03	---	2.63 ± 0.03
1831	1.4 ± 0.2	2.18 ± 0.02	---	2.16 ± 0.02

[a]Ref. 2.
[b]Ref. 4.

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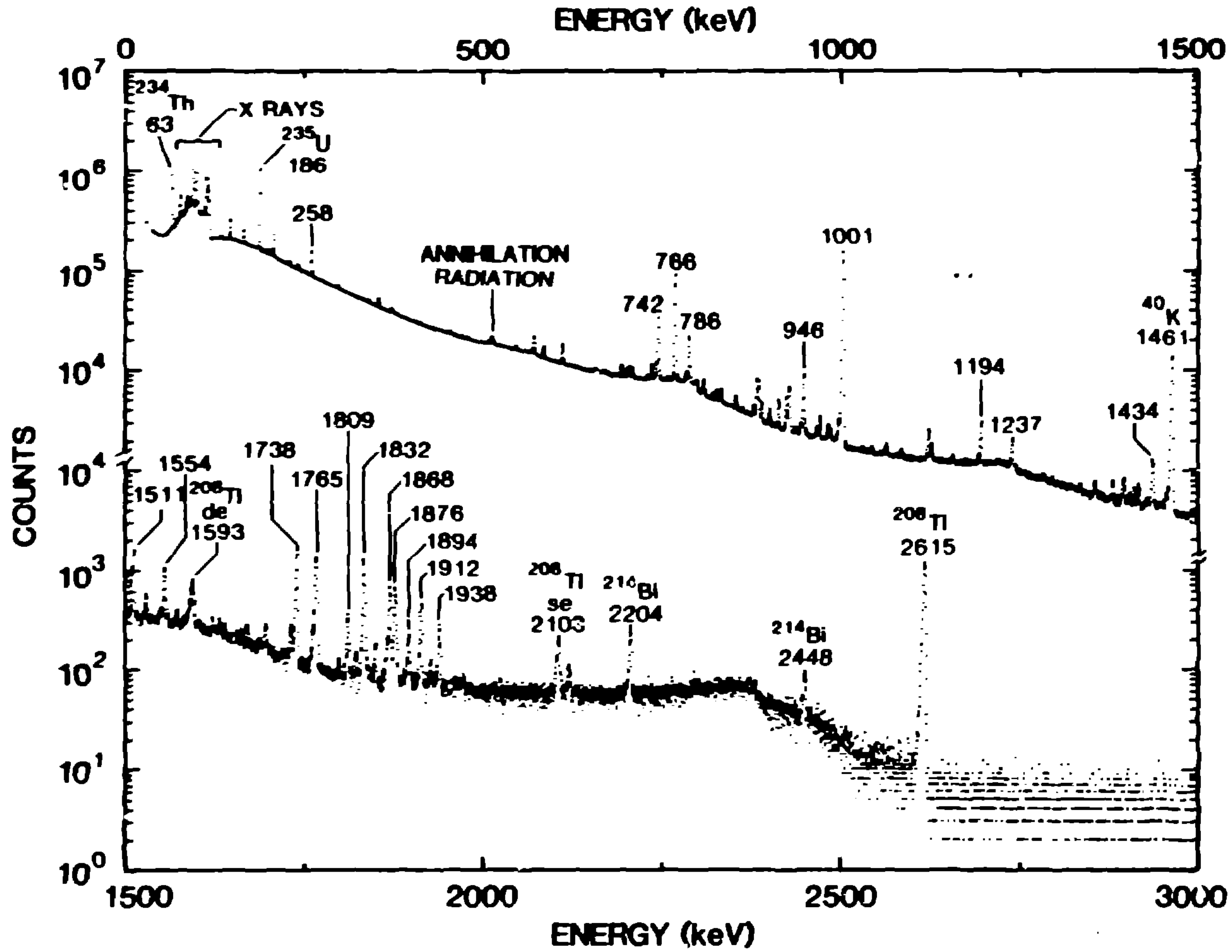

FIGURE 2 Pulse-height distribution from the 270.0 g sample of depleted uranium at 25 cm.